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Stellar Oscillations Network Group

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Abstract

Stellar Oscillations Network Group (SONG) is an initiative aimed at designing and building a network of 1m-class telescopes dedicated to asteroseismology and planet hunting. SONG will have 8 identical telescope nodes each equipped with a high-resolution spectrograph and an iodine cell for obtaining precision radial velocities and a CCD camera for guiding and imaging purposes. The main asteroseismology targets for the network are the brightest ($V < 6$) stars. In order to improve performance and reduce maintenance costs the instrumentation will only have very few modes of operation. In this contribution we describe the motivations for establishing a network, the basic outline of SONG and the expected performance.

Background and network motivation

After the discovery of the global solar oscillations in the 1970's it was quickly realized that long continuous observations were needed in order to obtain the best possible oscillation spectra. This ultimately led to the construction of several networks, such as BiSON (Chaplin et al. 1996), IRIS (Fossat 1991) and GONG (Harvey et al. 1996) dedicated to the observation of the solar p-mode oscillations.

In the study of oscillations in stars other than the Sun, the limitations of short observing periods are well known, leading to aliasing problems in the observed power spectra resulting from a poor window function, and low frequency precision caused by short observing runs.

As was the case for the solar oscillations the best way to overcome this problem is to obtain long observing runs with high duty-cycle, and this demands

either a groundbased telescope network or a space-based observatory such as CoRoT or Kepler.

During the past ~ 5 years several teams have demonstrated the successful detection of solar-like p-mode oscillations in other stars (Bedding et al. 2001, Bouchy et al. 2002) from time-series spectroscopy. The development of methods to measure high-precision velocities by groups hunting for extrasolar planets has made the direct detection of solar-like oscillations in other stars possible.

It is well known that the solar oscillations can be detected by measuring intensity variations or surface radial-velocity changes. In Fig. 1 we show the solar amplitude spectrum as measured in velocity (GOLF; Gabriel et al. 1995) and intensity (VIRGO; Fröhlich et al. 1995) by the SoHO satellite. We note that the background is dramatically lower for the velocity signal compared with the intensity signal, as already noted by Harvey (1988); this demonstrates that velocity observations will be most efficient in detecting oscillations in other stars. A further advantage of observing solar-like oscillations in radial velocity is that modes with $l = 3$ can be detected which is not possible for intensity observations.

The need for a network

As has been extensively discussed at this meeting asteroseismology has a great potential for increasing our understanding of stellar physics and evolution. The current instrumentation does not allow easy access to the facilities needed to provide long, un-interrupted velocity time series. At the same time with the remarkable precision reached at the best instruments, such as HARPS (Mayor et al. 2003), UVES (Dekker et al. 2000), UCLES (Walker & Diego 1985) and HiRES (Vogt et al. 1994) it is also clear that the access and availability of dedicated instrumentation is now the main limiting factor in the field. It is worth noting that the success of HARPS, UVES, UCLES and HiRES is due to the excellent quality of the instruments, more than a reflection of the primary mirror size. Thus a network dedicated to observing bright ($V < 6$) stars will need high-quality instrumentation, more than aperture size – this is a huge advantage in terms of cost, since aperture is one of the main cost-drivers for large-aperture telescopes.

A dedicated spectroscopic network will allow many different asteroseismic projects to be carried out, including both long-term projects for a few stars and short-term campaigns on several stars. Our simulations show that it will be possible to determine reliably the large and small frequency separations for solar-like stars in \sim one week of observations, which for example could be used to determine the ages of known planet-hosting stars and a significant fraction of the DARWIN mission targets, typically FGK-type main-sequence stars. On

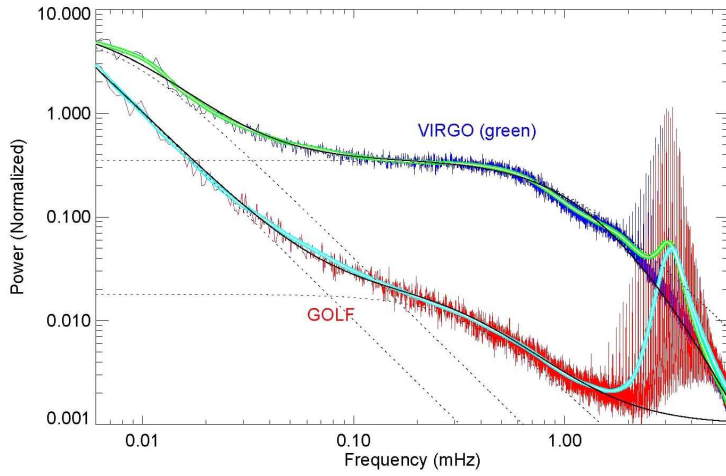


Figure 1: Comparison of data from VIRGO (green channel) and GOLF. The power is normalized such that the p-mode amplitude for $l = 1$ at peak power (near 3.1 mHz) is one for both VIRGO and GOLF. The background is dominated by granulation and activity. A simple Harvey model is used to describe the background (the different components shown as dashed curves). The diagram also contains the smoothed power for both VIRGO and GOLF. At high and low frequencies the p-mode signal-to-noise ratio (SNR) is almost the same for GOLF and VIRGO. One should also note that the intensity background at frequencies above 3–4 mHz is decreasing with frequency to the fourth power (which is not included in the Harvey model).

the other hand, observations over several months of a given star will allow very detailed investigations of stellar internal properties, utilizing also the expected reasonable SNR for even relatively low-order p modes whose frequency can be determined with very high accuracy. For many of the SONG targets it will also be possible to determine radii from interferometric observations which is a great help in the asteroseismic analysis.

Network baseline

To investigate whether a network such as SONG is realistic a conceptual design study has been carried out during 2006 at the University of Aarhus. Here we briefly describe the current (autumn 2006) baseline for SONG. One of the main risks associated with the construction of a network is the running costs and up-time of the instruments, and thus it is necessary to pay close attention to these

issues. As a consequence of this we aim to limit the number of components in the dome to avoid exposure to ambient conditions and have as few moving parts as possible which implies a limited number of operation modes.

The network will have 8 identical telescope nodes, four in each hemisphere, located at existing sites in order to avoid building significant new infrastructure. An illustration showing a possible location of sites is given in Fig. 2. Each instrument will be remotely controlled – for the long-term use of the network robotic observations are envisaged. It is, however, an extremely complex task to robotise a telescope and hence full automatization may not be achieved during the initial phases of operation.

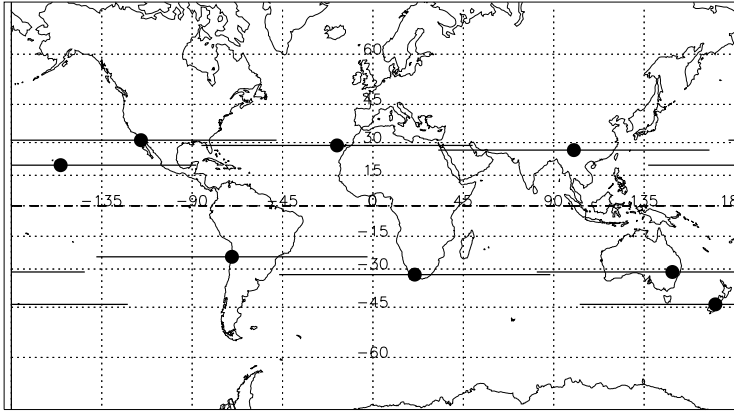


Figure 2: A possible distribution of SONG sites, with horizontal bars indicating the observability of an object which can be observed to ± 4.5 hours on either side of the meridian. For equatorial objects, which can be observed from both hemispheres, it would be possible to obtain ~ 60 hours of observation per 24 hours if all eight nodes were observing the same object. Note that there will always be at least two sites which can observe the same (equatorial) target, thus ensuring a high duty-cycle and valuable cross-checks on the measured velocities which will help to eliminate long-term drifts in the velocity zero points.

The conceptual design assumes telescopes with a diameter of 80cm and an alt-az mount with a Coudé focus, housed in a dome with a diameter of 4m. For the building we aim to use a standard 20 foot shipping container

in which the two main instruments (spectrograph and imaging camera) will be located at the Coudé focus. The dome/building configuration is similar in concept to that adopted by the Bradford Robotic Telescope on Tenerife (<http://www.telescope.org>). Our main motivation for choosing a Coudé focus is that this allows the dome to be completely empty, apart from the telescope, and to keep the instrumentation in a thermally controlled environment where all main components will be stationary – this will be beneficial for reducing maintenance.

Located at the focal station will be an optical table on which the instruments are mounted. The main instrument will be a high-resolution spectrograph optimized for precision radial-velocity work. As velocity reference we will use an iodine cell in an arrangement similar to that developed by Butler et al. (1996). The spectrograph will be thermally isolated and employ a UVES-like white-pupil design with a spectral resolution of 10^5 . An R4 echelle grating and a beam diameter of 75mm will result in a slit width of 1.5 arcsecond on the sky which will ensure a high throughput for most observing conditions. A $2K \times 2K$ detector with low readout noise and coatings optimized for the 500nm to 600nm region will be used to record the spectrum – this will possibly be a frame-transfer CCD which would allow a very high duty-cycle. The spectral coverage will be from 480nm to 670nm in order to cover the primary region of interest when using iodine and to also include the $H\alpha$ line. A preliminary optical design of the spectrograph carried out at the Anglo Australian Observatory shows that essentially diffraction-limited image quality across the detector can be achieved with very little variation of the line-spread function. It is planned to include also tip-tilt correction of the spectrograph feed in order to ensure maximum throughput and reduce the effects of guiding and tracking errors. The spectrograph will have a fixed setup, although we may include a few slits of fixed width to be able to change the spectral resolution. Figure 3 shows the basic outline of the telescope and focal plane.

In front of the slit an atmospheric dispersion corrector (ADC) will be implemented, as well as calibration lamps and the temperature controlled iodine cell.

Data are stored on-site for several weeks before being transported to a central institution; pipeline-reduced data will, however, be transmitted via the internet as soon as it has been processed by the data reduction pipeline.

Performance

We have made a detailed assessment of the spectrograph performance based on the AAO preliminary study and realistic numbers for seeing, slit width, mirror reflectivities and detector efficiency. The results are shown in Fig. 4 for a 75mm

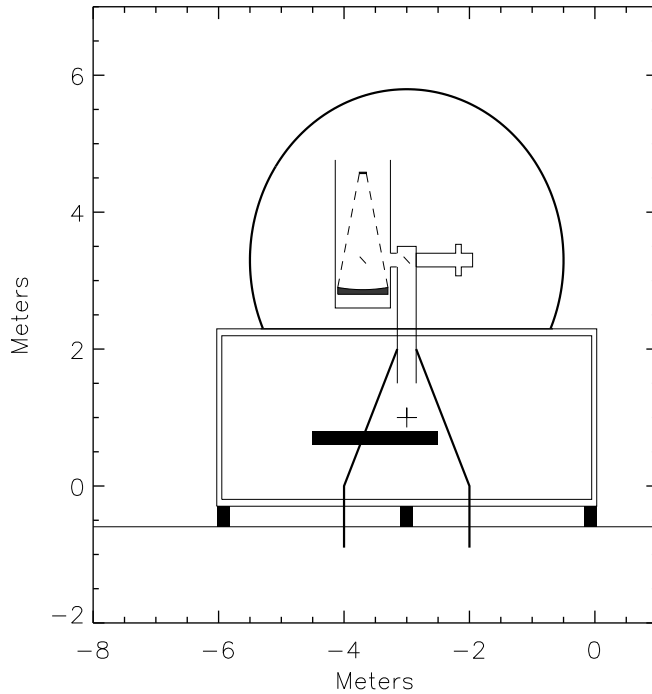


Figure 3: Schematic layout of a SONG telescope and enclosure. The telescope focus is shown as a cross near $(x, y) = (-3, 1)$ and the thick black bar is the optical table for the spectrograph and imager. The spectrograph and optical table will be thermally and mechanically isolated from the surroundings. Note that this design only uses 4 mirrors. The configuration shown here is essentially a German equatorial mount with the polar axis in a vertical position – this makes the design independent of the geographical latitude of the sites. The housing for the spectrograph is a standard 20 foot shipping container. Such containers are very rugged and easily available.

beam diameter spectrograph and a 1.25 arcsecond slit in 2 arcsecond seeing at an airmass of two.

This performance compares well with that of UVES on VLT as reported by Butler et. al. (2004). The main reason that SONG performs almost equally well as UVES on bright targets is the low duty-cycle for UVES due to the long detector readout time, compared with the integration time and to the narrow slit (0.3 arcsecond) needed to obtain the high resolution.

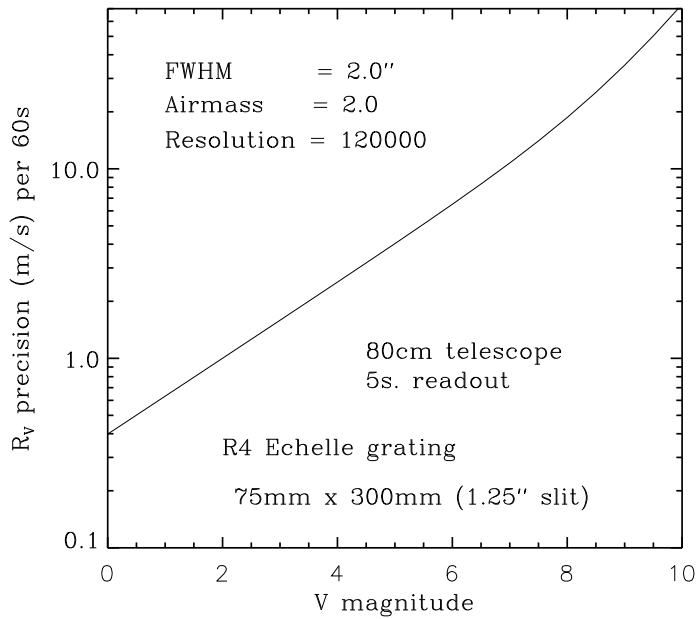


Figure 4: The predicted velocity precision for a single SONG node for a one minute observation versus the V magnitude of the observed star. A spectral type similar to α Centauri A and a slow rotation has been assumed. The echelle grating measures 75×300 mm, and the spectrograph has a collimated beam diameter of 75mm. The resolution with a 1.25 arcsecond slit is around 120,000.

With this performance we have carried out simulations for solar-like stars to see what would be required to estimate their ages based on the values for their large and small frequency separations. The simulations show that for stars brighter than $V \approx 5$ these can be accurately determined from a one week observing campaign.

Status and schedule

Currently (autumn 2006) SONG is nearly through its conceptual design phase. This is to be followed by detailed specifications and design of all components for a prototype during 2007. We plan to have an extended prototype phase (2008–2009) in order to eliminate all problems before going to full-scale operations, which is planned for around 2011–12.

At <http://astro.phys.au.dk/SONG> further information and contact addresses for SONG can be found.

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